Performance Comparison Between NiH_2 Dry Sinter and Slurry Electrode Cells

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ABSTRACT

The electrical and thermal performance of dry sinter and slurry process electrode cells manufactured for the Hubble Space Telescope (HST) batteries have been characterized for a matrix of operating conditions over the temperature range from 14 to 86°F at various charge control levels. The dry sinter process electrode cells tested are similar to the onboard HST NiH_2 cells. The slurry process electrode cells were developed to be less susceptible to electrode expansion and impedance changes with life. Both cell types were impregnated by the aqueous electrochemical process. Test conditions included standard capacity tests and electrical cycling using 96-minute cycling regimens incorporating constant depth-of-discharge (DOD) cycles. The dry sinter process electrodes have higher operating capacities to 1.20V/cell, but both electrode types have similar heat dissipation for the conditions tested. The results of the testing included cyclic heat generation during a typical 96-minute cycle, operating capacity data vs. cutoff voltage to generate a temperature-compensated voltage curve, and voltage characteristics suitable to develop a voltage prediction model. Analysis of data shows differences in the discharge voltage plateaus at all temperatures for the operating conditions evaluated. This is the basis for recommended changes in the battery charge control.

Background

The onboard HST batteries used dry sinter process positive electrodes as described by Nawrocki et al *(1)*. Those cells had original electrolyte pickup weights in the range of 280 to 300g throughout two stacks having 48 electrodes with 84 percent porosity for improved utilization and capacity performance. HST NiH_2 cells manufactured with slurry electrodes were developed at EPI in accordance with SOW LMSC/P096336 and battery cell specification LMSC/P106652 for the 1999 Servicing Mission Contract NAS5-5000. The cell design evolved from the heritage of HST, MILSTAR and other Air Force Mantech dry sinter cell designs with substantial flight experience. The slurry process cells have the same number of electrodes, each with 80 percent porosity and 3 to 6 percent less active material than the dry sinter electrode cell. Those cells contain approximately 20 to 30g less electrolyte per cell, and are less susceptible to electrode expansion leading to separator dry out and higher internal cell impedance with cycle life expected with dry sinter electrode cells. Both nickel electrode types were impregnated by the aqueous electrochemical process.

Lockheed Martin Missiles & Space (LMMS) and Eagle-Picher Industries (EPI) have conducted a series of characterization tests on Hubble Space Telescope NiH_2 cells for NASA/GSFC as reported by Rao et al *(2)*. The onboard HST NiH_2 battery cells manufactured with dry sinter electrodes had experienced capacity losses at a rate of approximately 4.5 Ah per battery per year of orbital operation from deployment in April 1990 until March 1996 as reported by Rao et al *(3)*. Some of the capacity loss was attributed to undercharging the batteries in the Hardware Charge Control (HWCC) mode following a safing event in March 1993. Data plotted in Figure 1 show battery capacity measurements since launch in 1990. The loss in battery capacity may be attributed to either battery degradation, operational voltage/temperature (V/T) charge termination level or a combination of both. Data plotted in Figure 2 show effects of temperature and cutoff voltage on capacity based on results of characterization testing on cells manufactured with dry sinter electrodes as described by Hafen and Armantrout *(4)*. Long term performance trends of capacity losses with operational time have been replicated in the ground test summarized in Figure 3. The loss in capacity has been observed in onboard batteries as well as in ground test batteries/cells as reported by Whitt and Brewer *(5)*. Of the various battery management options, operation on secondary heaters was implemented in November 1995; the battery capacity stability has improved as shown in Figure 1. Operation at other V/T levels is being considered and could be implemented as early as Servicing Mission 3 in 1999. The following section summarizes results of the previously reported characterization tests as well as results of an independent test run under isothermal conditions to compare with the characterization test results.

Test Results

The common or standard 80Ah IPV NiH_2 cells manufactured with slurry process electrodes have slightly higher thermal dissipation than dry sinter process electrode cells similar to those used on the HST batteries launched in 1990 as reported by Rao et al *(2)*. That study also showed that, for a worst case load at 18 amps both electrode types exceed the minimum mission safe mode capacity requirement of 225 Ah (45 Ah per battery for five batteries) with margin. The expected trend of decreasing operating capacity with increasing temperature was observed. Operating capacities increased only slightly with higher cutoff voltages.

An independent test has been run under isothermal conditions to compare with the characterization test results. Data shown in Figure 4 illustrate differences in heat dissipation in watts versus slope of V/T charge termination levels for various operating conditions. It can be seen that increasing the slope from 62mV/°C to 97mV/°C reduces heat dissipation (Q) as temperature rises for these conditions. Load levels ranging from 5.1Ah to 9.6Ah per rev were evaluated to reflect differences between HST high load (HL) conditions and low beta safe mode loads described as very low loads (VLL). These various operational load levels were tested as part of an investigation of a battery thermal instability event in July 1997. The HL condition had 9.6Ah/rev load with 14A charge to V/T charge termination with 2A trickle charge, and the VLL/2S condition had 5.1 Ah/rev load with 23A/14A/0A charge to V/T. The on-orbit thermal anomaly battery heat rejection versus recharge ratio data shown in Figure 5 correlates well with VLL/2S testing at LMMS. The thermal instability was probably caused by overcharging from some combination of the following:

- Higher charge current and V/T charge termination levels
- Increased charge times associated with higher beta angles and sun time
- Lower battery charge efficiencies with cycle life

Figures 6 and 7 show relative heat dissipations versus operating capacities for various V/T levels with a 9.6Ah load for both slurry and dry sinter process electrodes, respectively. Figure 8 shows relative performance characteristics for slurry cells at a 5.1 Ah load level. Sensitivity to two-step (2S) and multiple-step (MS) charge control can be seen in this figure relative to heat dissipation for a given V/T level. It can be generally concluded that the V/T charge termination curve slope is not optimized for the HST NiH_2 batteries. Excessive overcharge from higher charge currents and V/T levels are contributing to thermal instability along with other factors. Operation at lower V/T levels and lower temperatures appears to provide sufficient capacity margin for on-orbit cells manufactured with dry sinter process electrodes as reported by Rao et al *(2)*. Periodic capacity measurements are required to assess long term performance trends as recommended by Armantrout and Hafen *(6)*. The following section summarizes conclusions and recommendations for future battery charge control operations.

Conclusions/Recommendations

The voltage/temperature (V/T) charge termination curve slope was developed for NiCd batteries and is being optimized for NiH_2 batteries. V/T testing under projected operating conditions indicates HST energy need of 225 Ah (45 Ah per battery for five batteries) during safe mode operations can be met with cells manufactured with either slurry or dry sinter process electrodes similar to those used on the HST batteries launched in 1990. Slurry cells have slightly higher thermal dissipation than dry sinter process electrode cells as previously reported by Rao et al *(2)*. Battery temperatures increase for either cell type during periods of high sun time and during safe mode events.

There is need to improve HST battery charge control in order to:

- Improve battery thermal stability.
- Curtail battery heating in safe mode.
- Control and/or minimize battery capacity loss.

Several corrective actions under consideration to reduce overcharge include the following:

- Conditioning the sensed battery voltage by one level allowing a lower effective V/T charge termination level during safe mode operation.
- Implementing a multiple-slope and V/T level option in the charge controller allowing for selectable V/T levels to control recharge ratios.

Cost and schedule considerations along with extra vehicular activity (EVA) safety issues are currently being evaluated to determine the most cost effective solution. Further system testing on six 5-cell packs at MSFC is planned to validate any changes to the V/T slope curve. An assessment whether to replace batteries in 1999 was made late in 1997. It is presently planned to replace the HST batteries, launched in 1990, during the Servicing Mission 4 in 2002.

References

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Figure 1. HST Battery Capacity Trend Data

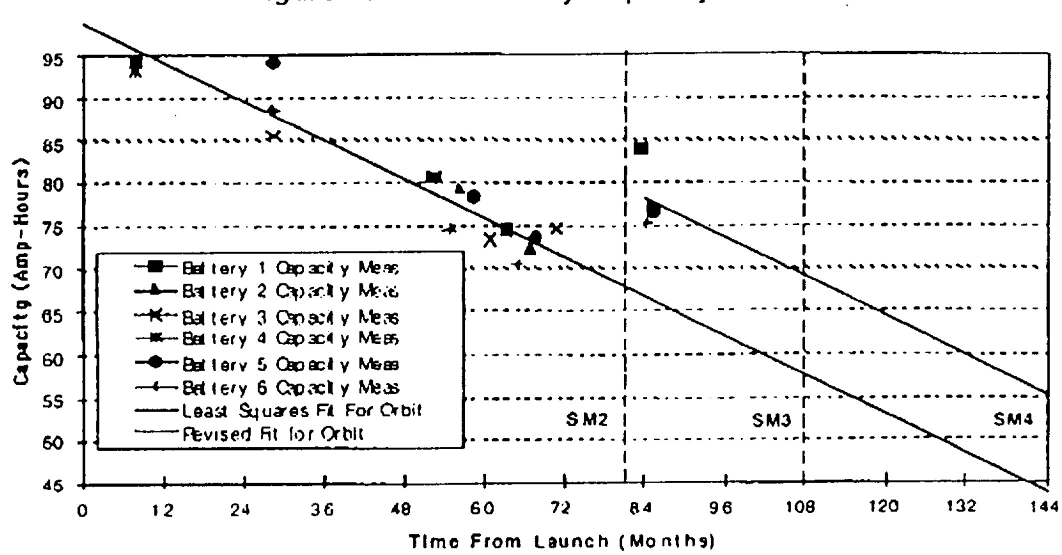

Figure 2. Effect of Temperature and Cutoff Voltage on Capacity
(Charge Current is 15 amperes)

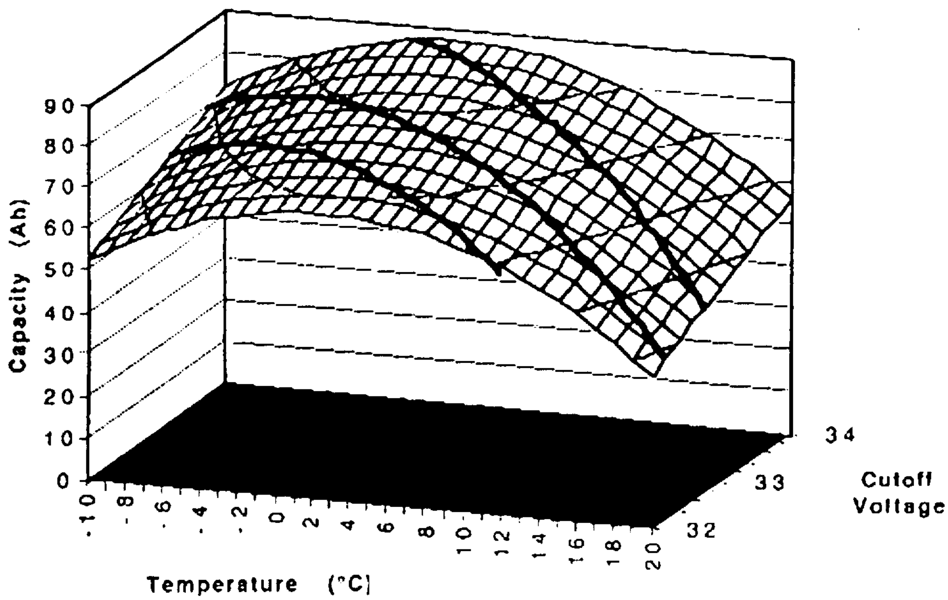

Figure 3. Ground Test Capacity Data

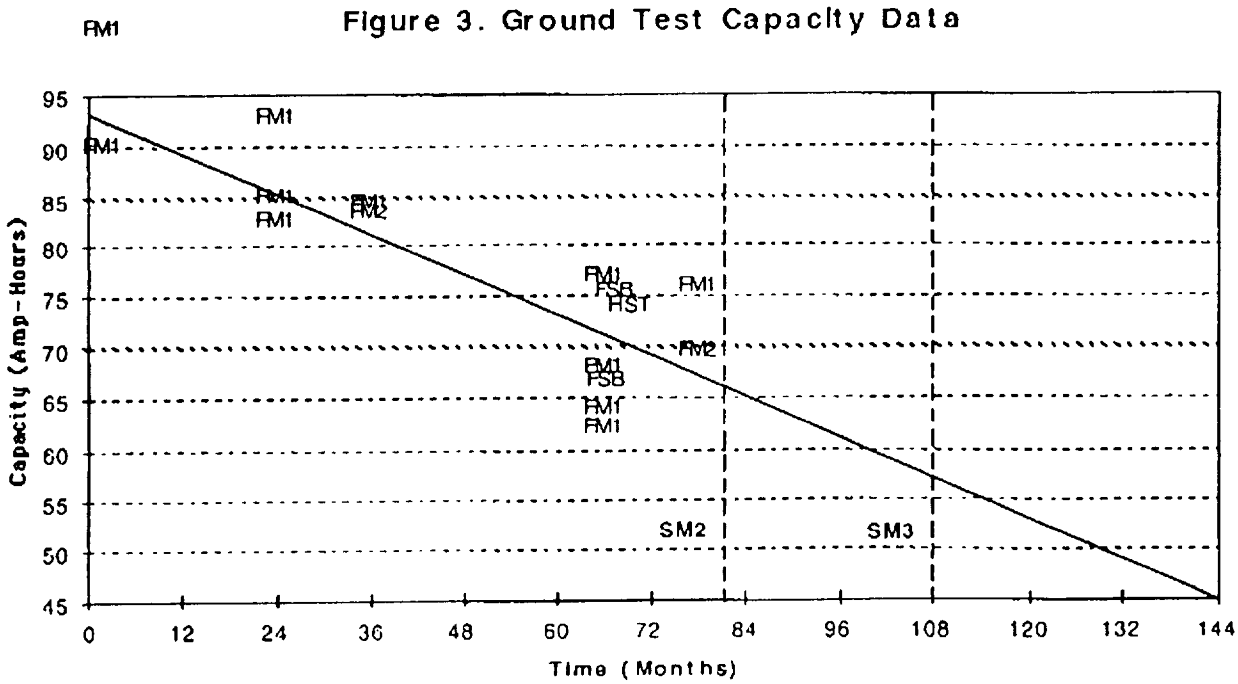

Figure 4. HEAT DISSIPATION IN WATTS VERSUS SLOPE OF VT CURVE

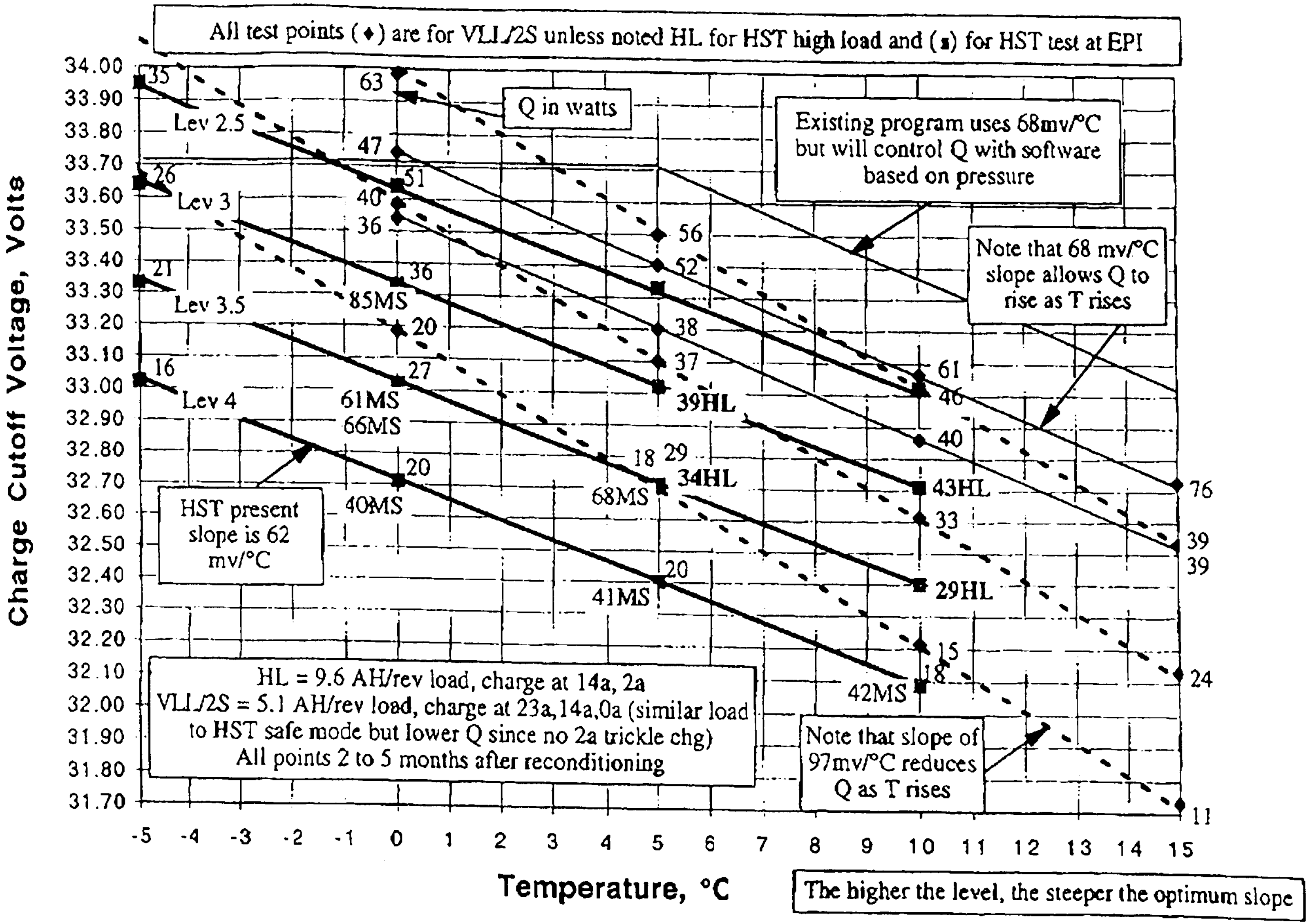

Figure 5. HEAT DISSIPATION vs RECHARGE RATIO FOR VLL RUNS

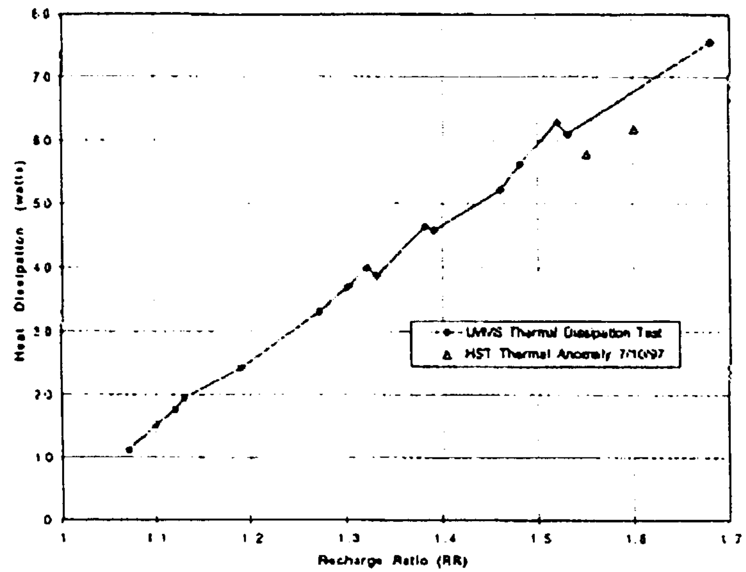

Figure 6. HEAT DISSIPATION VS. OPERATING CAPACITY FOR SLURRY CELLS LOADED AT 9.6 Ah

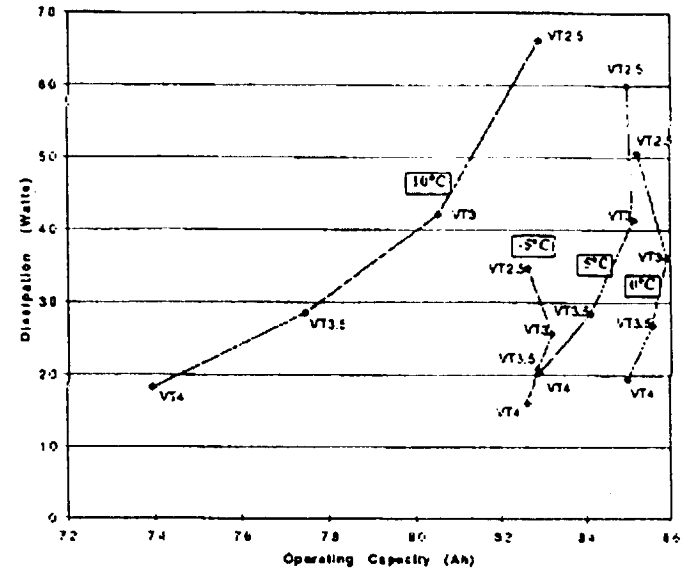

Figure 7. HEAT DISSIPATION VS. OPERATING CAPACITY FOR DRY SINTER CELLS LOADED AT 9.6 Ah

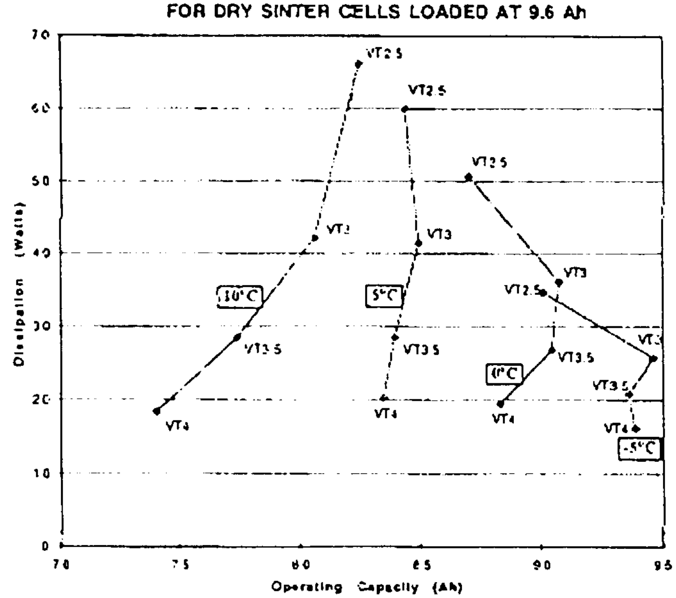

Figure 8. HEAT DISSIPATION VS. OPERATING CAPACITY FOR SLURRY CELLS